Mutual Coupling Reduction for Linearly Arranged MIMO Antenna

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***Abstract*— In the present paper, a new technique to reduce mutual coupling between linearly arranged patch antenna array is presented. Antennas are arrange in close space with edge-to-edge separation of 0.096λ and center-to-center spacing of 0.29λ, where λ is the free space wavelength. Two separate rectangular shape and T-shape parasitic elements are used to cancel the surface current (SC) in order to reduce mutual coupling. The parasitic elements are placed in between the antennas with an extension of the T-shape towards the boundary of patches. The obtained results indicate that mutual coupling for two consecutive antennas are less than -15 dB over the entire bandwidth.**

Keywords—patch antenna, parasitic elements, surface current (SC), mutual coupling

I. INTRODUCTION

Due to the increasing demand of high data rate for wireless communications, multiple-input multiple-output (MIMO) antenna has become a hot topic over the last two decades. Mutual coupling is a key factor in MIMO that adversely affects the performance of the antenna. This factor can be reduced by increasing the spacing between the antennas. However, modern communication systems often requires compact MIMO devices. Thus, mutual coupling is usually inevitable [1]. Different techniques have been developed to reduce mutual coupling for compact MIMO antennas. For examples, defected ground structures (DGSs) was used to reduce mutual coupling in [2], [3]. It is an effective way to reduce coupling but the appearance of back lobes can seriously affect the front-to-back ratio, which can be a serious issue for, e.g., base station antennas. In [4], electromagnetic band gap (EBG) structure was used to increase the isolation performance. However, the EBG structure requires certain spacing between two antennas. Shorting vias can be used to suppress the surface wave and tune the polarization of a patch antenna [5]. Thus, orthogonal polarized antennas with low mutual coupling can be achieved using this technique. Nevertheless, it is difficult to extend this technique to multi-port antennas with more than two antenna elements. Metasurface walls were used to suppress the radiation coupling at the cost of increased profile [6]. In [7], slotted complementary split ring resonator (SCSRR) was used to reduce mutual coupling. Neutralization line [8] and decoupling network [9] have been shown to be effective mutual coupling reduction techniques. Yet, the implementation complexity increases with number of antennas. In [10], a parasitic element was used on the substrate material in order to obtain an effective decoupling by multilayer structure.

In this paper, we reduce the mutual coupling of a MIMO antenna by placing parasitic elements in between the antennas. The parasitic element consists of two parts: a rectangular loop and a T-shape loop. We consider a compact MIMO antenna in this work. The spacing between the consecutive antennas is rather smaller, i.e., edge-to-edge separation of 0.096λ and center-to-center spacing of 0.29λ. The proposed structure is inserted in between every two adjacent antennas (see Fig. 1). Thanks to the proposed decoupling structure, an isolation of more than 15 dB is achieved over the entire bandwidth, with 10-dB isolation enhancement at the center frequency (5.8 GHz).

II. DECOUPLING STRUCTURE OF MIMO ANTENNA

We consider four linearly arranged microstrip patch antennas as depicted in Fig. 1. The patch Antennas are fed by coaxial cables. The inner and outer diameter of coaxial cable is 1.2mm and 4.1mm respectively. The dielectric in between the inner and outer conductors is Teflon (PTFE) with permittivity of 2.1. The probe is located at a distance of 1.5 mm below the center of the patch. The MIMO antenna is design to operate at frequency of 5.8 GHz with a common substrate and ground plane. The substrate is commercially available material of Rogers RO4350B with relative permittivity of 3.48 and height of 1.524mm. The length and width of substrate is Ls=80mm and Ws=30mm respectively. Ground is of the same length and width as the substrate, while the height of the ground is 0.02mm. The rectangular patch has dimensions of Wp=12.67mm and Lp=10mm. The edge-to-edge distance of two adjacent antennas is 5mm (0.096λ); and the center-to-center distance is 15mm (0.29λ).

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The two parts of the decoupling structure (i.e., rectangular loop and T-shaped loop) are shown in Fig. 2. The dimensions of the rectangular loop are L_1=18.1mm, L_2=1.2mm, L_3=0.25mm, L_4=0.3mm. The dimensions of the T-shaped loop are L_5=12.35mm, L_6=0.3mm, L_7=0.7mm, L_8=0.33mm, L_9=5mm, L_{10}=0.3mm, L_{11}= 1mm, L_{12}= 0.3mm, L_{13}=7mm, L_{14}= 0.3mm, L_{15}=6.2mm, L_{16}= 0.28 mm and L_{17} =2.2mm.

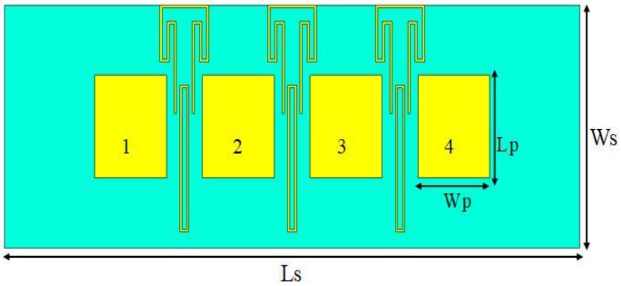

Fig. 1. Proposed MIMO antenna array structure

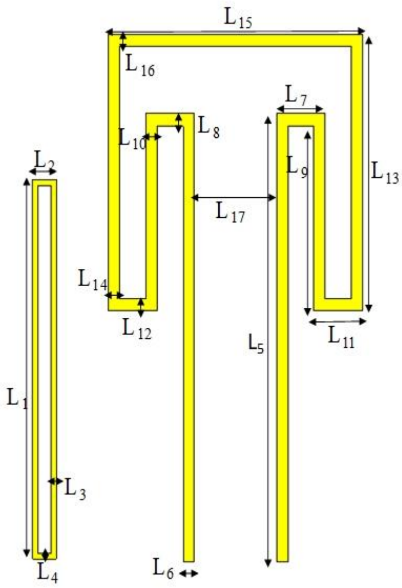

Fig. 2. Proposed decoupling structure, rectangular shape (left) and T- shape (right)

III. DECOUPLING MECHANISM

Generally, when the spacing between multiple antennas is less than λ/2, it results into a serious performance degradation due to the presence of strong mutual coupling. To improve the isolation performance of such antennas, a T-shaped loop and a rectangular loop are placed between two antennas to suppress the mutual coupling. The length of the T-shaped loop is chosen to be resonating at around 5.9 GHz. Fig. 3(a) presents the S-parameters by inserting the T-shaped loop in between antenna elements 1 and 2. The deep at 5.9 GHz in the S_{21} curve is due to the resonating nature of the T-shape loop. Analogously, Fig. 3(b) presents the S-parameters by inserting the rectangular loop in between antenna elements 1 and 2. It can be seen that the rectangular loop itself has little effect on the decoupling performance, but when combined with the T-shaped loop, it helps enhance the isolation by shifting the resonance frequency of the T-shaped loop towards the center frequency of the antenna.

Fig. 4 shows the absolute surface currents without decoupling structure, when port 1 is excited while others are terminated with 50-ohm resistance. The coupling currents can be observed in the nearby elements.

It is illustrated in Fig. 5 that by introducing the decoupling structure, the surface currents are confined within the vicinity of radiating element and the parasitic elements. Therefore, it can be concluded that the decoupling structure is responsible to interrupt the coupling currents.

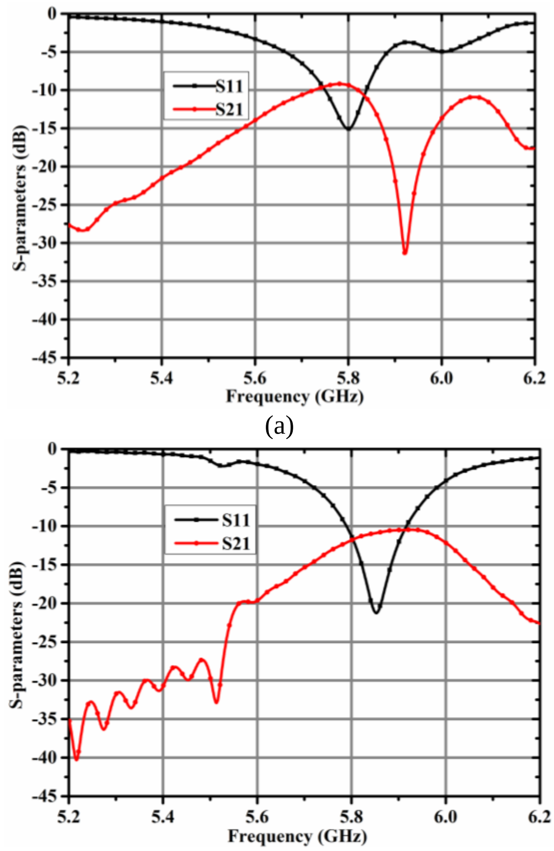

Fig. 3. Scattering parameters: (a) T- shape loop; (b) Rectangular shape

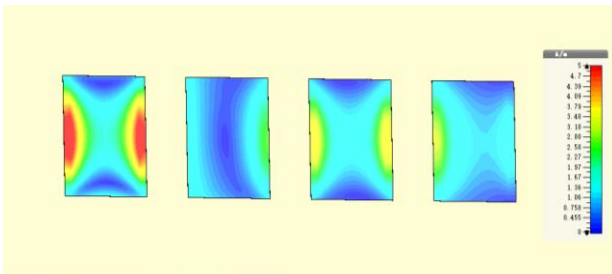

Fig. 4. Surface current distribution without decoupling structure

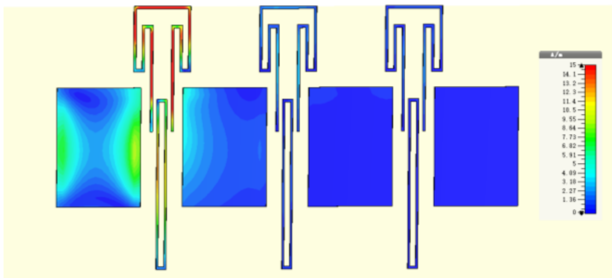

Fig. 5. Surface current distribution with decoupling structure

IV. Simulation Results and Discussion

Fig. 4 shows the values of reflection coefficient of the MIMO antenna with the proposed decoupling structure. Because of the symmetrical structure, only S_{11}, S_{22} are shown in Fig. 4. The bandwidth is defined as the frequency range over which the reflection coefficient is below -10 dB. Fig. 5 compares the mutual coupling coefficients without and with decoupling structure. Without the decoupling structure, the values of S_{21}, S_{31}, and S_{41}, are -9dB, -12.1dB, -12.7dB at 5.8 GHz, respectively. With decoupling structure, the corresponding values are -19dB, -28.7dB, -37.8dB at 5.8 GHz, respectively. The worst mutual coupling coefficient is reduced from -9 dB to -19 dB, i.e., a 10-dB improvement at 5.8 GHz. It shows that good isolation of 15 dB is achieved between adjacent antennas over the entire bandwidth.

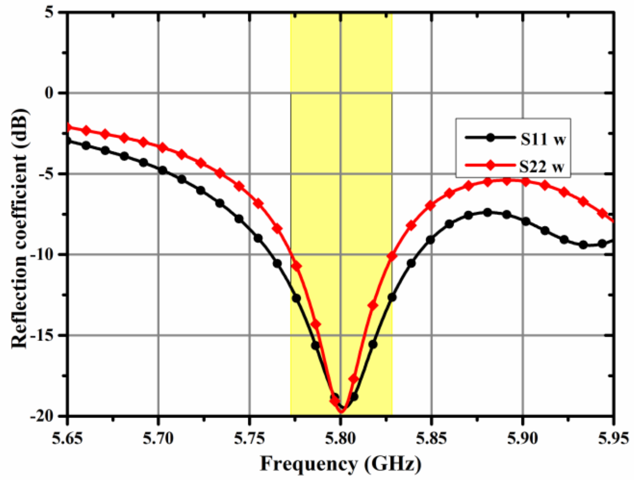

Fig. 6. Reflection coefficient with (w) decoupling structure

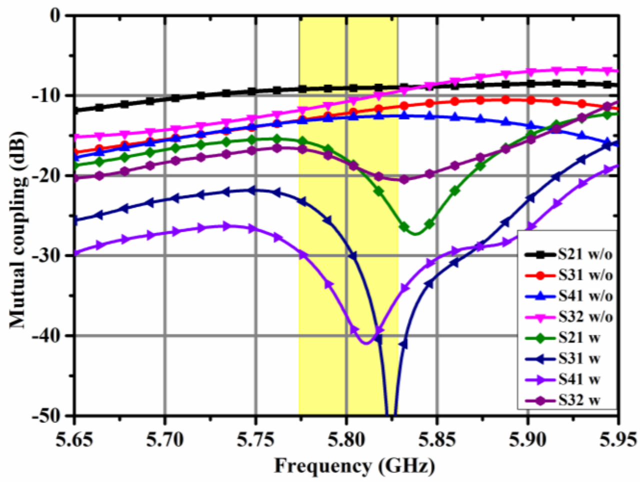

Fig. 7. Coupling coefficient without (w/o) and with (w) decoupling structure

V. Conclusion

In this paper, a decoupling structure is proposed to reduce the mutual coupling of a compact MIMO antenna. The decoupling structure reduce the worst mutual coupling by 10 dB at 5.8 GHz. A good isolation of more than 15 dB is achieved over the entire bandwidth.

References

[1] X. Chen, S. Zhang, Q. Li, "A review of mutual coupling in MIMO systems," *IEEE Access*, vol. 6, pp. 24706 - 24719, 2018.

[2] J. Li, Q. Chu, Z. Li, and X. Xia, "Compact dual band-notched UWB MIMO antenna with high isolation," *IEEE Trans. Antennas Propag.*, vol. 61, no. 9, pp. 4759–4766, Sep. 2013.

[3] X. Chen, M. Abdullah, Q. Li, J. Li, A. Zhang, and T. Svensson, "Characterizations of mutual coupling effects on switch-based phased array antennas for 5G millimeter-wave mobile communications," *IEEE Access*, vol. 7, pp. 31376-31384, 2019.

[4] F. Yang and Y. Rahmat-Samii, "Microstrip antennas integrated with electromagnetic band-gap (EBG) structures: A low mutual coupling design for array applications," *IEEE Trans. Antennas Propag.*, vol. 51, no. 10, pp. 2936–2946, Oct. 2003.

[5] M. Abdullah, X. Chen, Q. Li, and A. A. Kishk, "Mutual coupling and correlation of closely spaced patch antennas," *Electron. Lett.*, vol. 55, 2019.

[6] A. Dadgarpour, B. Zarghooni, B. S. Virdee, T. A. Denidni, and A. A. Kishk, "Mutual coupling reduction in dielectric resonator antennas using metasurface shield for 60-GHz MIMO systems," *IEEE Antennas Wireless Propag. Lett.*, vol. 16, pp. 477-480, 2017.

[7] M. M. B. Suwailam, O. F. Siddiqui, and O. M. Ramahi, "Mutual coupling reduction between microstrip patch antennas using slotted-complementary split-ring resonators," *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 876-878, 2010.

[8] S. Zhang and G. F. Pedersen, "Mutual coupling reduction for UWB MIMO antennas with a wideband neutralization line," *IEEE Antennas Wireless Propag. Lett.*, vol. 15, pp. 166-169, 2016.

[9] L. Zhao, L. K. Yeung, and K.-L. Wu, "A coupled resonator decoupling network for two-element compact antenna arrays in mobile terminals," *IEEE Trans. Antennas Propag.*, vol. 62, no. 5, pp. 2767–2776, May 2014.

[10] S. Maddio, G. Pelosi, M. Righini, S. Selleri, and I. Vecchi, "Mutual coupling reduction in multilayer patch antennas via meander line parasites". *Electron. Lett.*, vol. 54, pp. 922-924, 2018.